Microwave-based Diagnostics and Sensors for High Explosives Applications

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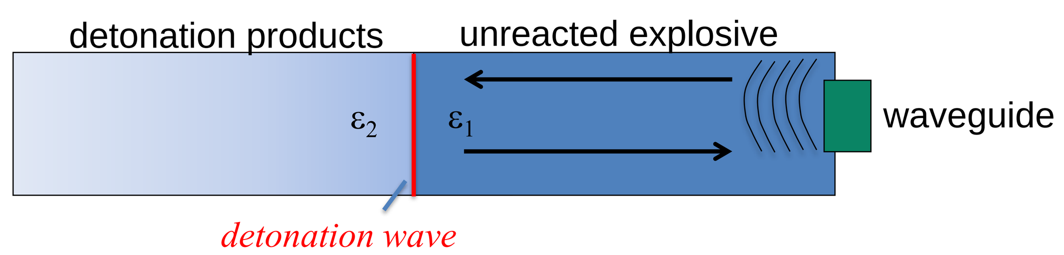
Microwaves are well suited for non destructive evaluation of dielectric materials such as explosives due to their combination of good penetration depth and short wavelengths. We present work on two classes of microwave inspections: direct measurement of detonation fronts via microwave interferometry (MI), and microwave interrogation of additively-manufactured passive embedded sensors.

Detonation Front Interrogation



- Many explosives of interest are electrically insulating and therefore are transparent to microwave radiation.
- At detonation and deflagration fronts, the high density of ionized species creates a dielectric discontinuity.
- Microwave signals reflected from this discontinuity can be analyzed to measure the front velocity.
- Microwave Interferometry (MI) provides measurement of round-trip phase change/Doppler frequency:

Path length change $\Delta l_\lambda = \frac{0.5 * \Delta\phi}{2\pi}$ Velocity (m/s) $= \frac{\Delta\phi}{\Delta t} * \frac{0.5\lambda}{2\pi}$

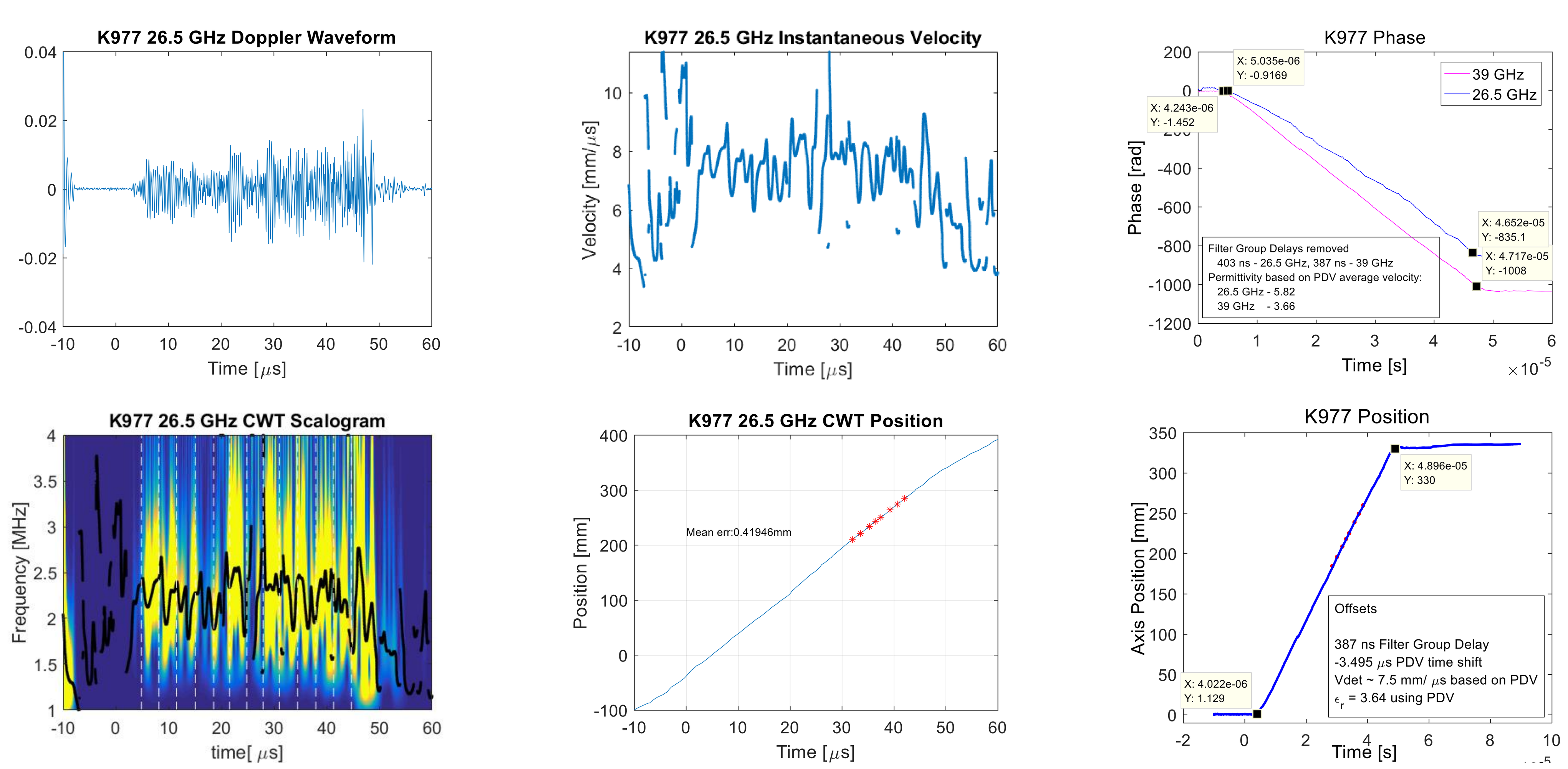
MI on Detonator-Initiated Cylinder Tests

- Experiment carried out in a copper cylinder.

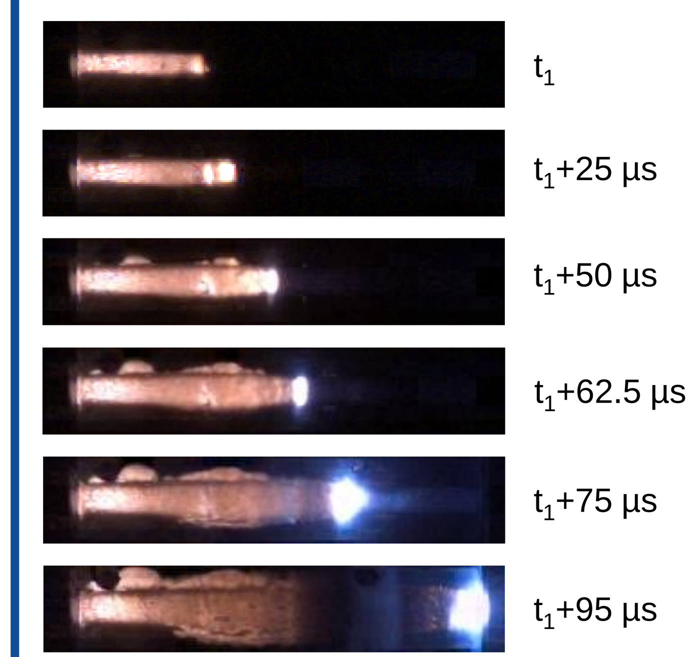
  - Velocity measurement via external PDV probes.

  - Strong reflected microwave signal.

- Microwave system successfully tracks the detonation front for the duration of the experiment.
- Velocity determination is dependent on knowledge of the explosive's dielectric properties.



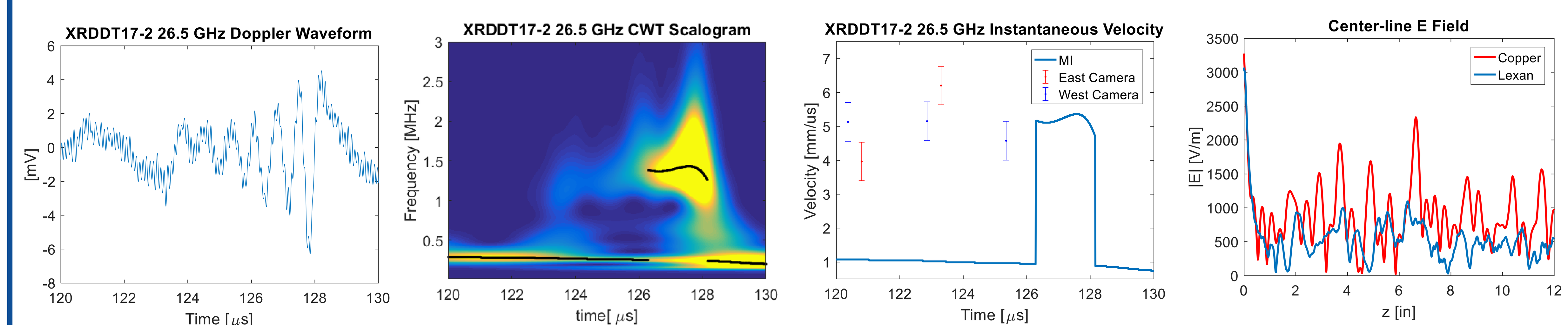
MI on Deflagration-to-Detonation Transition Tests



- Transition from slow-moving, low density deflagration to fast-moving, high density detonation front.
- Experiment conducted in transparent, non conductive cylinder.

  - Allows for velocity measurement via high-speed camera.

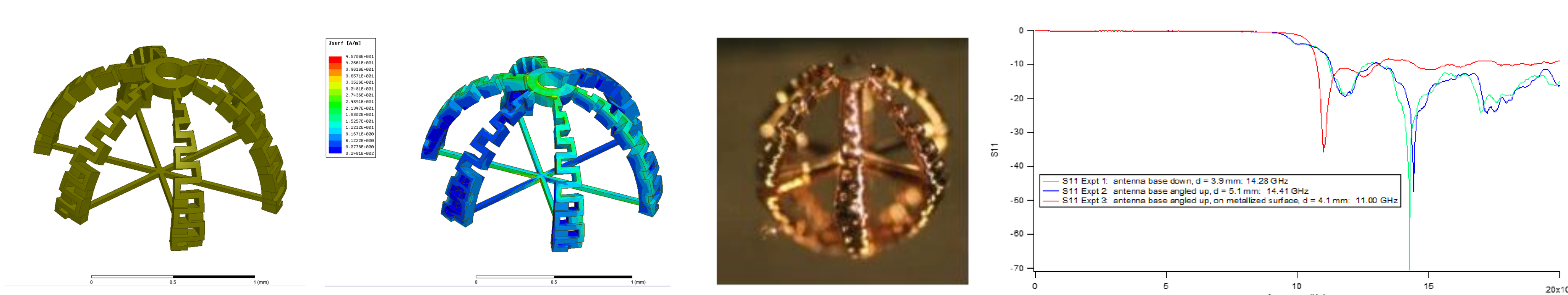
  - Results in reduced reflected microwave signal.



Measured signal · Measured spectrum · Measured velocity · Simulated electric fields

Passive Embedded Sensor Development

- Electrically small 3D antennas coupled with capacitive or piezoresistive materials are embedded in the material.
- Additive manufacturing allows for orientation-independent antenna design.
- Pressure and temperature changes are observed by the corresponding changes in resonant frequency of the antenna due to capacitance or resistance changes in the sensor material.
- Multiple closely-spaced sensors can be distinguished by separating their operating frequencies.
- Pure backscatter measurement; sensor does not require power source or read-out electronics.



Antenna design · Simulated electric fields · Fabricated antenna · Antenna measurement results

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